Resin tapping in *Pinus pinaster*: effects on growth and response function to climate

Mar Génova · Leocadia Caminero · Javier Dochao

Abstract *Pinus pinaster* is of great ecological and economic importance and has traditionally been subjected to intensive uses such as wood and resin extraction. In the last decade, dendrochronological methods are increasingly being used to analyze the effects of climatic factors on the growth of the maritime pine, although tapped trees were generally avoided because it was thought that their growth was affected by resin extraction. In Spain, however, it is hard to find a long-lived forest of *P. pinaster* that has not been subjected to tapping for resin. In the present paper, we performed dendrochronological analyses of this species from wood cores and cross sections taken from both resin-tapped trees and resin-untapped trees killed by a fire in 2008 in the central Iberian region. On the one hand, we reconstructed the history of forest management by means of analysis of resin scars in the cross sections of resin-tapped trees. This facet of dendrochronological dating had not heretofore been developed, and little is therefore known about it. We dated 46 scars, which indicate a history of intensive resin extraction in the 1920–1950 period. Moreover, we attempted to answer the question: Have the old resin extractions in *P. pinaster* precluded the use of their growth rings for dendrochronological and dendroclimatic studies? We found that resin extraction did not alter general short-wavelength variability, and we developed a local chronology with all synchronized series, and the response function with respect to climate is similar to other oldest *P. pinaster* forests studied in Spain. The information we have recorded can be of use for providing tools to land managers for interpreting forest dynamics in resin-tapped regions.

Keywords Dendrochronology · Forest management · Resin scar · Response function · Spain

Communicated by H. Pretzsch.

M. Génova (✉) · L. Caminero · J. Dochao
Departamento de Producción Vegetal: Botánica y Protección Vegetal, Escuela de Ingeniería Técnica Forestal, Universidad Politécnica de Madrid, Avda. de Ramiro de Maeztu s/n, 28040 Madrid, Spain
e-mail: mar.genova@upm.es

Introduction

Pinus pinaster Ait. (maritime pine) is of great ecological and economic importance in the Iberian Peninsula and has traditionally been subjected to intensive uses such as extraction of resin and wood (Farjon 2008; Rodríguez et al. 2008; Calama et al. 2010). The natural range of *P. pinaster* spans the western Mediterranean basin, the largest forests being located in Spain and Portugal (Costa et al. 1997; Alcalde et al. 2006). In Spain, resin tapping constituted an important rural activity from the 1840s until the 1970s, when low prices made its exploitation economically unviable. During this period, resin from *P. pinaster*, the pine most often tapped for resin, became one of the most important non-timber products (Rodríguez et al. 2008; Calama et al. 2010). Thus, like many coniferous trees in Eurasia, as well as in North and South America, *P. pinaster* has a history of resin tapping and presents innumerable scars on the trunks, thus providing evidence of this activity (Schweingruber 1996).

Some scientific forest studies have evaluated and modeled the resin yield in Spain (Nanos et al. 2000, 2001; Tadesse et al. 2001), but very few studies have analyzed the incidence of resin extraction on tree growth (Rodríguez et al. 2008). At present, increased demand for natural resins has pushed up prices, and several previously abandoned Spanish stands are once again being tapped (Nanos et al. 2000; Calama et al. 2010). This makes it more interesting to study the history of resin tapping, by means of a retrospective analysis of the resin scars, and to analyze the effect of resin tapping on tree growth and vitality.

The species *P. pinaster* had rarely been used for dendrochronological and dendroclimatological studies until the end of the twentieth century, because stands older than 100 years are very hard to find, trees from the lower mountain level often present false rings, and most trees have been damaged by resin harvesting in the past (Schweingruber 1993). However, in the last decade, dendrochronological methods are increasingly being used to analyze the effects of different factors on the growth of the maritime pine. Studies have been conducted on stands in southwest France (Timbal 2002), the west coast of Italy (De Micco et al. 2007), coastal Tunisia (El Khorchani et al. 2007), the northwestern Iberian Peninsula (Rozas et al. 2011; Vieira et al. 2009), central and central-eastern Spain (Bogino and Bravo 2008; Candel-Pérez et al. 2012) and the mountains in southeastern Spain (Sánchez-Salguero et al. 2010). In general terms, they are quite young forests, very few of them surpassing 100 years of age (Bogino and Bravo 2008). Detailed studies have been conducted on intra-annual fluctuations in wood density (IADFs) and their relationship with regional and large-scale climatic factors (De Micco et al. 2007; Bogino and Bravo 2009; Vieira et al. 2009; Rozas et al. 2011) as an expression of polycyclism, one of the characteristic adaptations to intermittent favorable conditions for vegetative growth (Alía et al. 1997). Tapped trees were generally avoided because it was thought that their growth could have been affected by resin extraction, which could confound possible climatic signals (Bogino and Bravo 2008). However, in central and southern Spain, it is hard to find a long-lived forest of *P. pinaster* that has not been subjected to tapping for resin.

We recently conducted a dendrochronological study of a natural forest of maritime pine located in central Spain that had previously been subjected to resin tapping and which presented long-lived resin-tapped trees (RT trees) and resin-untapped trees (RU trees). The preliminary results showed that the RT trees presented growth patterns that were synchronic with the RU trees and that they could be used jointly to establish chronologies and for analyzing the effects of climate on growth (Caminero 2009; Génova and Caminero 2009). Unfortunately, there was a big fire in the region in the summer of 2008, and all the trees in the study area were killed by the fire. We analyzed cross sections of some trees selected from this forest (RT trees and RU trees) in order to construct tree-ring chronologies of both types of trees and to date the resin scars observed inside the sections of the RT trees.

Numerous dendrochronological studies state the dating of hidden scars inside the trunk caused by fire or geomorphological events (McBride 1983; Van Horne and Fule 2006; Stoffel et al. 2010; Díez-Herrero et al. 2012, among many others), even in subfossil wood (Lageard et al. 2000), but no studies reliably date resin scars by means of cross-dating.

Therefore, the main objectives of the present paper involve:

- Testing the usefulness of RT trees in dendrochronological and dendroecological studies.
- Comparing growth differences between RT trees (disturbed) and RU trees (undisturbed) throughout time.
- Using the resin scar record to establish the forestry history of resin-tapped regions.
- Providing tools to land managers for interpreting forest dynamics in resin-tapped regions and using these tools for planning the management activities.

Study area

The area studied is located in the mid-Duero basin at the transition with the Central System Range, in the mid-mountain area known as *La Serrezuela de Pradales*, in the municipality of Moral de Hornuez (Segovia). It constituted a low elevated *horst* during the alpine orogeny and is currently flanked by the rivers Riaza and Duratón (Fig. 1).

The main substrates include Triassic sandstones, conglomerates and clays, with very well-drained soils, and the climate is continental Mediterranean, characterized by irregular rainfall, between and within years, and high summer temperatures.

The site studied (923 ha, 41°29′–41°27′N, 3°37′–3°40′W and 1,120–1,300 m above sea level) has been managed since 1948; it is publicly owned and used for forestry. The main tree species is *P. pinaster*. There are also isolated specimens of *Quercus faginea* Lam. and *Quercus ilex* L., and *Juniperus communis* L. and *Juniperus thurifera* L. develop throughout the area, but they are more abundant in the higher zones presenting calcareous soils. The underbrush exhibits a high density of *Cistus laurifolius* L., isolated shrubs of *Thymus mastichina* (L.) L., *Lavandula stoechas* L., *Helichrysum serotinum* Boiss., *Halimium umbellatum* (L.) Spach and *Artemisia campestris* L., and in the low zones, there are some isolated specimens of *Rosa* sp. The scant herbaceous stratum comprises *Corynephorus canescens* (L.) Beauv., *Vulpia myuros* (L.) C.C. Gmelin and *Vulpia bromoides* (L.) Gray.

Resin extraction constituted an important activity in the area since the start of the nineteenth century, although it was finally abandoned in 1982. As in the rest of Spain, the resin extraction system mostly employed was the Hugues method, that is, forming concave resin faces by extracting a part of the wood, which requires specialized labor and produces a low yield (Rodríguez et al. 2008).

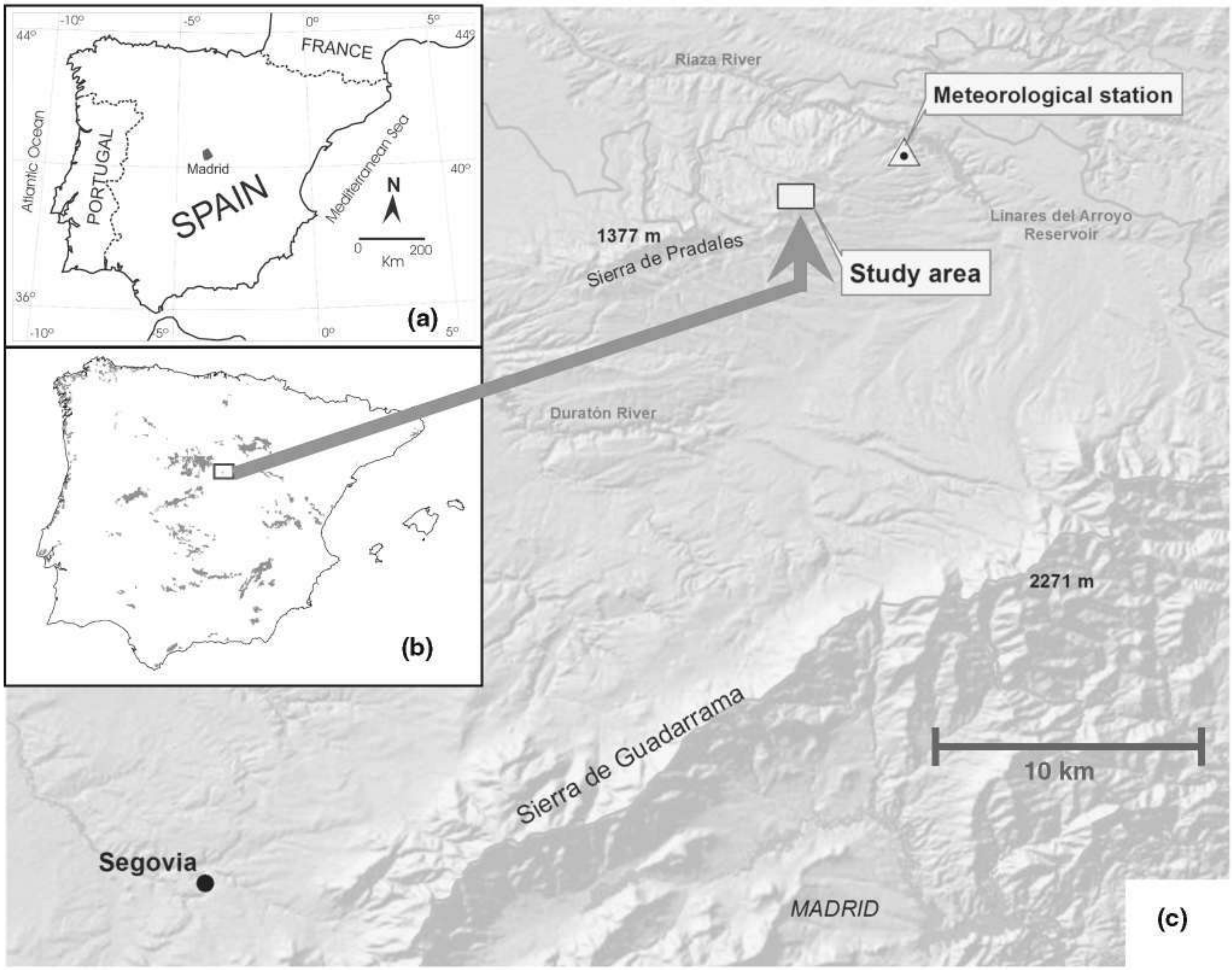

Fig. 1 Location of the study area. Iberian Peninsula (**a**), natural Spanish distribution of *P. pinaster* (Alcalde et al. 2006) (**b**), sampling site and meteorological station (**c**)

Moreover, this pine forest has primarily been subjected to regenerative felling, although there has been no major management since 1954, apart from exceptional fellings such as those of 1972–1981 or 1983, 1987–1989, 1991 and 1992, the year in which the greatest amount of cutting took place (Servicio Territorial de Medio Ambiente y Ordenación del Territorio de Segovia 1992). The forest was totally burnt in summer 2008. Less than a year after the fire, the dead trees were cut down and reforestation is currently underway.

Materials and methods

We located, selected and analyzed samples of the oldest trees in order to reconstruct the longest possible period of exploitation of the pine forest. The samples are from dominant trees in good physical condition and large sized before the fire, ranging in diameter at breast height (DBH) from a minimum of 49 cm to a maximum of 134 cm (see "Appendix"). Although we attempted to select the same number of RT trees and RU trees, many of the old trees presented resin scars, and we finally collected samples according to their representation in the forest as a whole: RT trees (70 %) and RU trees (30 %).

Some of the samples are tree-ring cores extracted in years prior to the fire. Two samples per tree were taken at normal height, approximately 1.30 m above the ground (Caminero 2009; Génova and Caminero 2009). Other samples are whole sections of the log cut at a height of approximately 15 cm above the forest floor, provided by the Castilla y León Regional Government, since trees were cut down 1 year after the fire. We noted the principal dendrometric and ecological data from each selected and georeferenced tree, both in trees selected for core extraction on dates previous to the fire and in trees that were burnt but still standing and which we selected for analysis of the cross sections (Table 1, "Appendix"). On the outside of the RT trees, we observed from one to ten resin faces.

For the cross sections, preparing the samples involved a laborious process, mainly due to the large size of some of them, which reached a perimeter of somewhat over 4 m ("Appendix"). Each sample was surfaced with a power planer and then sanded with a belt sander and a series of increasingly finer grit belts.

We identified the resin scars in the cross sections by their particular morphology: They present a concave shape, due to being made according to the Hughes resin extraction system, and they exhibit a circumference arc of approximately 10–12 cm long (Fig. 2).

Once the samples were dried and prepared, we measured the rings (with an accuracy of 1/100 mm) with the Lintab measuring system and associated Tsap software (Rinn 2003). In the cross sections, we made a minimum of four measurements per sample, corresponding to four or more radii, and they therefore represented the different variations in growth. In the cross sections from the RT trees, we made a large amount of measurements depending upon the number of scars: Apart from complete radii in areas unaffected by resin extraction, we made other measurements that enabled more accurate dating of the resin scars. On the one hand, we measured the growth rings from the bark to the edges of the scar and on the other from the resin scar to the pith, keeping in mind that the wound starts to close in the year/s after the one in which the resin scar was caused (Fig. 2).

We conducted the synchronization and subsequent dating of the growth series by means of several visual, graphic and statistical techniques (Cook and Kairiukstis 1990) and checked these using Cofecha software, a program for cross-dating and measurement quality control (Holmes 1992a). Throughout this process, we identified and corrected anomalies that prevented correct synchronization: absent or discontinuous rings or multiple rings. Apart from dating each of the resin scars identified in the cross sections, we analyzed pointer years and releases and suppressions.

We selected the pointer years using a double criterion (Génova 2012):

a. The years in which the growth values are differentiated from the immediately previous one in a proportion greater than, or equal to, 20 % (LRM program, Holmes 1992b). We only selected pointer years over 75 % of the series analyzed.
b. The years in which the growth values represented a decrease or an increase in one or more standard deviations.

Table 1 Characteristics of the samples analyzed

	N trees (cores/sections)	Mean age (year)	MRW (mm)	MS	CM
RT trees	24 (11/13)	109.7 ± 21.2	2.38 ± 0.55	0.25	0.67
RU trees	12 (6/6)	93.5 ± 20.2	2.78 ± 0.69	0.23	0.64

RT trees resin-tapped trees, *RU trees* resin-untapped trees, *MRW* mean ring width, *MS* mean sensitivity, *CM* mean correlation with master (Cofecha program)

We used the program Jolts (Holmes 1999) to detect brusque medium-frequency oscillations (release and suppression) appearing synchronously in numerous trees and determined the occurrence, coincidence and characteristics of these changes in tree growth. If changes affect a large number of trees and other factors cannot be identified, it is highly likely that these changes are indicators of the effects of forestry treatments (Lorimer and Frelich 1989) involving past management and canopy history, as has been determined, for example, in some Spanish forests (Rozas 2004; Génova 2007; Génova and Moya 2012). Finally, we evaluated and contrasted the average growths of both groups of trees (RT trees and RU trees), as well as the most significant variations in growth. Local chronology was obtained by standardizing the individual sequences with spline models and applying the robust mean with the program Arstan (Cook and Holmes 1996).

The meteorological data used were provided by the Linares del Arroyo Station (Fig. 1), the nearest one to the site (41°31′N, 3°34′W and 911 m above sea level), whose precipitation and temperature records started in 1943 and 1962, respectively. In relation to mean annual temperature (11.71 °C), the Linares del Arroyo meteorological station does not present significant variations throughout the interval considered, except in two periods (1971–1975 and 1991–1993) in which these temperatures fall below the average. It should be noted, however, that we did observe a gradual increase in mean springtime temperatures from 1992 to the present time, which have been above the average from 1999 to the present (Fig. 3). We observed a great degree of variability in annual precipitation (minimum 262 mm, maximum 737 mm and mean 455 mm). Two periods stand out with precipitation above average (1956–1967 and 1992–2003) and two others below (1944–1955 and 1969–1976). Springtime precipitation, however, is much less variable (Fig. 3).

The relationship between growth and climate was determined by means of bootstrapped response function using the program DendroClim2002 (Biondi and Waikul 2004). We analyzed the relationship between mean monthly temperature and total monthly precipitation in the period ranging from August of the previous year to October of the current one. We thus availed of 30 variables (15 average monthly temperatures and 15 total monthly precipitations) and a time span of 45 years (1963–2007).

Results

We analyzed samples from 36 pine trees (resin-tapped and resin-untapped) that no longer exist due to being destroyed during the 2008 fire. Table 1 presents the general data on both groups of trees.

In general terms, cross-dating presented no particular problems. The most common growth anomaly involved the existence of discontinuous rings in six of the complete sections analyzed, corresponding mostly to RT trees. This accounts for 16 % of the trees studied and 0.13 % of the total number of rings measured. In general, there is no coincidence between the specimens in relation to dates presenting discontinuous rings, except in 1992, when there is a coincidence between discontinuous rings in two of the specimens analyzed. As for multiple rings, we only identified one in tree number 28, which had been developed around the whole circumference.

Dating of resin scars

We dated in the available cross sections 4 46 resin scars corresponding to 13 trees in the 1913–1960 period. A greater or lesser degree of accuracy in dating the resin scars generally depended upon the response time of the local cambium to the damage and therefore to the formation of discontinuous rings. Almost all of the resin scars were made from 1920 to 1950, and a higher percentage (70 %), from 1920 to 1940 (Fig. 7).

It should be noted that this type of scar takes a long time to be healed, e.g., a resin scar made in 1933–1934 took, at least, 75 years to heal (Fig. 2).

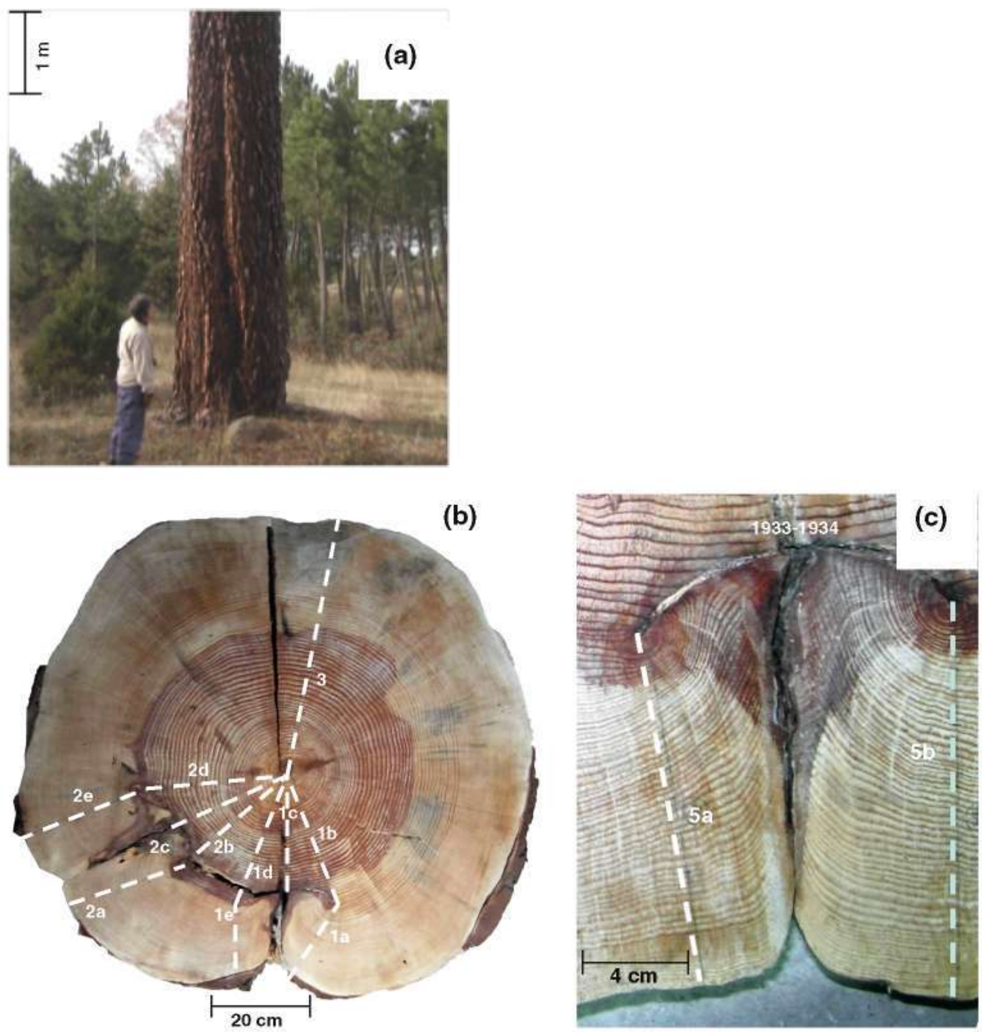

Fig. 2 One of the largest specimens of *P. pinaster* used in our study prior to the 2008 fire; behind this specimen appear young regenerated trees (**a**). Measurements taken in a cross section presenting two resin scars (**b**). Resin scar almost completely healed; the scar healed due to protection by the resin during the formation of the scarring edges on both sides of the resin face (**c**). Each measurement was identified by a resin-scar number and a letter

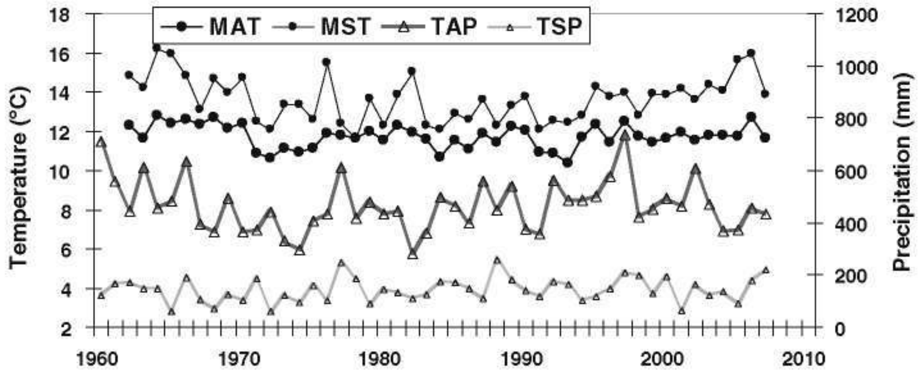

Fig. 3 Oscillations in temperature and precipitation of the Linares del Arroyo meteorological station. *MAT* mean annual temperature, *MST* mean spring temperature, *TAP* total annual precipitation, *TSP* total spring precipitation

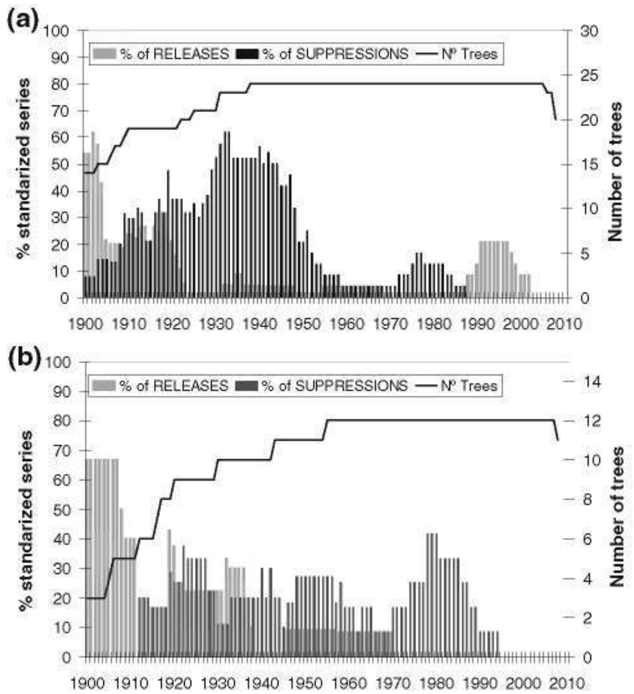

Fig. 4 Percentages of standardized tree-ring growth series indicating changes in medium-frequency trends (the *black columns* represent suppressions, and the *gray ones* represent releases) and number of trees analyzed per year (*solid black line*). **a** Resin-tapped trees, **b** resin-untapped trees

Analysis of differences in growth between the RT trees and the RU trees

Analyzing the differences between the RT trees and the RU trees (Table 1), we determined that:

- Average age is somewhat greater in the RT trees (109.8 years $\pm$ 21.2) than in the RU trees (93.5 years $\pm$ 20); *t* test, *p* value $= 0.0168$.
- Average ring width (MRW) is greater in the RU trees (2.78 mm $\pm$ 0.69) than in the RT trees (2.38 mm $\pm$ 0.55); *t* test, *p* value $= 0.0325$.

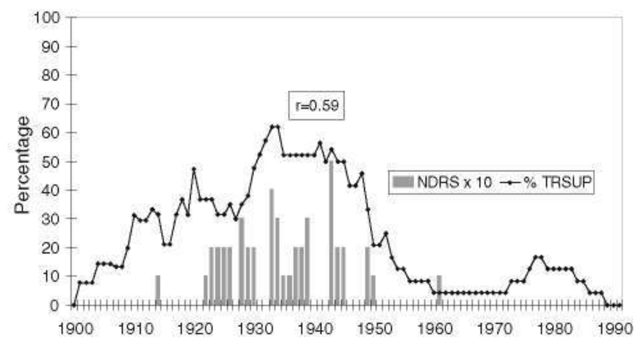

Fig. 5 Percentage of suppressions (% TRSUP) and number of dated resin scars (NDRS) in resin-tapped trees indicating the *r* value

- In relation to mean sensitivity (MS) and to mean correlation with master (CM), we found no big differences: 0.25 and 0.67, respectively, for the RT trees compared with 0.23 and 0.64 for the RU trees.

Furthermore, we analyzed the different growth tendencies over time in the two groups defined (RT trees and RU trees), identifying the periods in which significant changes occur (releases and suppressions) affecting over 25 % of the trees. In both cases, the release periods are similar and take place mainly in the first two decades of the twentieth century, except in the 1932–1936 period, which was only significant in the RU trees. As for the suppression periods, 1916–1948 was highly significant and 1930–1944 was particularly so, when over 50 % of the RT trees showed sharp decreases in growth, whereas in the RU trees the most significant suppression periods are 1919–1927, 1948–1956 and 1974–1987 (Fig. 4).

It should be noted that the growth suppressions determined in the RT trees were very directly related to the dates of resin scars ($r = 0.59$, $p = 0.00$, Fig. 5).

Figure 6 shows the yearly averages of growth for RT trees and RU trees. The contrast between both defines a heterogeneous period up to the start of the 1930s of the twentieth century and certain clear differences in growth throughout the

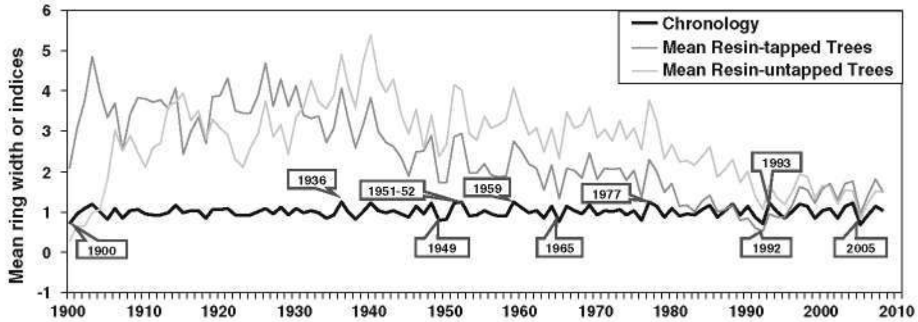

Fig. 6 Annual growth averages in RT trees and RU trees, local chronology of Hornuez and the most significant pointer years in the *boxes*

Table 2 General characteristics of the residual chronology of Hornuez and of variability in the common interval time span (last row)

Time span	NT		MS		SD	AU
1857–2008	36		0.13		0.124	−0.03
	NT	MCT		SNR	EPS	VFE
1928–2007	29	0.57		38.18	0.97	59 %

NT number of trees, *MS* mean sensitivity, *SD* standard deviation, *AU* autocorrelation order 1, *MCT* mean correlations between trees, *SNR* signal-to-noise ratio, *EPS* expressed population signal, *VFE* variance in first eigenvector

following decades up to the end of the century which were estimated at 33 % for this period. In the final decade analyzed (corresponding to the first one of the twenty-first century), growth rates become stabilized and are very similar.

Despite the differences observed, the different synchronization indicators used show that the variations in growth follow very similar tendencies and a marked common pattern for all the trees (Table 1; Fig. 6, "Appendix"). Thus, for example, the pointer years are the same in both groups: Particularly, negative values appeared in 1900, 1949, 1965, 1992 and 2005 and positive ones in 1936, 1951–1952, 1959, 1977, 1993 and 2003. Moreover, the partial chronologies created with the RT trees and the RU trees (results not shown) present no significant differences between them during the common period.

As we established that resin extraction did not alter the general short-wavelength variability, we developed a local chronology (1857–2008) with all synchronized series (Table 2), which can be compared with the remaining chronologies for this species and others in the region and can be used in future studies.

Relationship between growth and climate: response function

As it was found that the response function is the same for the partial chronologies with RT trees and RU trees (results not shown), we present the results obtained with the common chronology in Fig. 7.

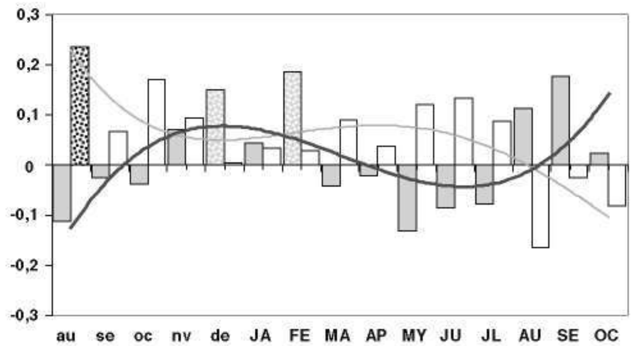

Fig. 7 Bootstrap response values of the Hornuez chronology to mean monthly temperature (*shaded* and *unshaded columns*) and precipitation (*empty columns*) of the Linares del Arroyo meteorological station. Year of initiation: 1963, final year: 2007. The window starts in August of the previous year (*lower case*) and ends in October of the current year (*upper case*). *Columns dotted* indicate significant values (95 % percentile range): August precipitation of the previous year, December temperature of the previous year and February temperature of the current year. The *continuous gray line* shows the tendency of the correlations with monthly precipitation and the *black line* with mean monthly temperature

In general terms, the correlations between the chronology of Hornuez with mean monthly temperatures and monthly precipitations are balanced and opposed (particularly in the current year). The correlations with the monthly precipitation of the current year are positive, except in the summer and autumn months, in which they provide an accumulation of reserves for the following year, and there is therefore a highly significant relationship between the ring width and August precipitation of the previous year. As for temperatures, the sign of the correlation varies according to the seasons and is generally positive in winter (mean February temperature being the most significant) and negative in spring and summer of the current year.

Forest dynamics and history

The chronology determined for the Hornuez pine forest ranges from 1857 to 2008, although just over half the trees germinated at the start of the twentieth century ("Appendix"). Many of the old trees in the Hornuez forest presented resin scars: 70 % of the RT trees compared with 30 % of the RU trees. The RT trees presented higher radial growth rates than the RU trees at the start of the twentieth century. By contrast, during the most intensive resin-tapping period, determined as the decades from the 1920s to the 1950s of the twentieth century, these tendencies are inverted and the RU trees grow more on average up to the end of the twentieth century (Fig. 6). Since the start of the twenty-first century, both groups exhibit very similar growth rates. Likely, the extensive cuttings (the latest dated in 1992) had reduced competition and had favored higher growth rates in RT trees, together with the fact that no resin was extracted in the final decades.

Discussion

The present paper explores for the first time the potential of the resin-scar analysis for reconstructing forest management history, increasing the different types of events dated by means of scar analysis. We present the dating of 46 resin scars in 13 trees of *P. pinaster* in central Spain, indicating a history of intensive use of the forest, particularly in the 1920–1950 period. Furthermore, the presence of these resin scars is very directly related to the growth suppressions determined in the RT trees for this same period. The long period of suppressions from 1916 to 1948 in the RT trees fits with the dating of the vast majority of the scars. Ballesteros et al. (2010), analyzing scars in *P. pinaster* trees caused by flash-flood processes, also determined a significant decrease in ring widths close to the cambial damages, among other anatomical changes that were not studied in our work.

The history of resin extraction can be reconstructed from the date when the scarring began (Schweingruber 1996), but the growth sequences of a forest managed for resin tapping provide a great opportunity to study and reconstruct the effects of resin tapping on the growth and survival of the trees, as well as those of other possible effects related to the forest management system. In the Hornuez pine forest, the RT trees presented higher growth rates than the RU trees at the start of the twentieth century (Fig. 6). Perhaps, the former were chosen as RT trees due to their bigger sizes, whereas the RU trees were not used due to the fact that they were suppressed or defective trees. Resin tapping in this forest was especially intensive in the 1920–1950 period, and the most recent evidence of this practice is the scar dated in 1960, although in the fourth review of the Management Project (Servicio Territorial de Medio Ambiente y Ordenación del Territorio de Segovia 1992), resin tapping is shown to have continued up to 1982. Perhaps in these years, other trees in the forest were tapped, which have not been analyzed.

We were unable to analyze a similar number of samples of RT trees and RU trees, due to bias caused by sampling old trees in an exploited pine forest. The sampling, however, was representative of the oldest cohort in the forest. Throughout a 70-year period (from the 1930s to the end of the last century), we determined a clear difference between the ring width of the RT trees and the RU trees, which is estimated at 33 %, which coincides with the general estimated reduction of 25–33 % in the growth of *P. pinaster* due to resin tapping in Spain (Rodríguez et al. 2008). It should be noted that although resin tapping was stopped in the trees studied at the end of the 1950s, for at least 40 years more, the average width of the growth rings remained lower in the RT trees than in the RU trees. Increased demand for natural resins has pushed up prices and a few abandoned stands of *P. pinaster* are therefore being tapped once again (Nanos et al. 2000; Calama et al. 2010). Information about the effects of resin tapping and other uses on the growth of *P. pinaster* in central Spain will be of great interest with regard to planning resin tapping.

Regarding the pointer years determined, we only found coincidences with other Spanish pine forests in the negative value of 1965 and the positive one of 1959 (Génova 2012), as well as in the negative value of 2005, which, at least in central and southeastern Spain, was very dry (Sánchez-Salguero et al. 2010; Candel-Pérez et al. 2012). The extreme negative pointer year of 1992 (presenting in all studied pines) coincides with the date of the last most extensive cutting in the area. This abrupt width change could be related to pruning or other damages that would have disturbed the tree growth studied. Then, RT and RU trees turn growth rates stabilized and were very similar, especially in the first decade of the twenty-first century. This favorable change in the growth of the RT trees can be attributed, in terms of management, to the latest and most extensive cuttings, which have reduced competition, and also to the fact that no resin has been extracted in recent decades.

The chronology of the Hornuez *P. pinaster* forest (1857–2008) was consistent within the longest ones established for this taxon on the Iberian Peninsula (Bogino and Bravo 2008, 2009; Vieira et al. 2009). The descriptive statistics showed that, for example, mean sensitivity (0.21) and variance in first eigenvector (59 %) agree within the range determined for other chronologies in central Spain (Bogino and Bravo 2008, 2009) or on the Atlantic littoral of Portugal (Vieira et al. 2009).

The significance of the relationship between climate and the ring width of maritime pine has been established in numerous areas of the Iberian Peninsula (Bogino and Bravo

2008; Vieira et al. 2009; Rozas et al. 2009; Sánchez-Salguero et al. 2010; Candel-Pérez et al. 2012). We have shown that the response function of the Hornuez pine forest is similar to that reported by Bogino and Bravo (2008) for the oldest pine forest on the Mediterranean Coast and in the ecoregions of Catalonia and Aragon and that the radial growth in Hornuez is positively correlated with precipitation during the current year, except in the summer and autumn months, and very significantly related to prior August. In relation to temperature, the response of the trees in Hornuez varies according to the season, and we can highlight the positive association with February temperature which, among the sites studied by Bogino and Bravo (2008), only occurs at lower altitudes. Although it should be kept in mind that in the present paper, the response function analyses the period in which there is no evidence of resin tapping, the effects thereof lasted for many more years, thus reducing growth but did not, however, affect the growth–climate relationships. By way of a conclusion, we demonstrate that it is possible to build chronologies with old RT trees, whose resin scars are old, and to analyze in these chronologies the relationship between growth and climate, providing coherent results.

The forest we studied was destroyed by a fire, and the managers are now facing the challenge of ecologically restoring the land it occupied. *P. pinaster* originated on, and is distributed throughout, the Iberian Peninsula, from where it spread along the mountain ranges (Gil 1991), becoming diversified in numerous populations with their own genetic characteristics (González-Martínez et al. 2004; Sánchez-Gómez et al. 2010; de Miguel et al. 2012). The different responses to climate established for the center, the Mediterranean area and the Atlantic coast of the Iberian Peninsula (Bogino and Bravo 2008; Vieira et al. 2009; Rozas et al. 2009; Sánchez-Salguero et al. 2010; Candel-Pérez et al. 2012), also indicate marked differences with regard to adaptation to very diverse climate conditions, which should also be considered in ecological restoration, with seeds being selected from the regions of origin (Alía et al. 1996).

The use of historical knowledge provides long-term perspectives for understanding ecological patterns and processes in plant communities and for determining their historical range and variability for evaluation thereof and for decision-making in ecological restoration programs. Although the new ecological restoration theories promote restoration efforts that are not exclusively limited to accurately reconstructing what had previously existed, but rather can thrive in the context of future changes, it still remains essential to know as precisely as possible the forest's history (Choi 2004, 2007; Jackson and Hobbs 2009). The present study of the Hornuez pine forest evaluates, over a 100-year period, the resin-tapping periods and the effects of this activity on tree growth, as well as those of other uses and management systems together with the effects of climatic factors. All this information can be very useful for ecological restoration and future planning of the area studied.

Acknowledgments This research was partially funded by the Senscom (CGL2008-06005), Dendro-Avenidas (CGL2007-62063) and Dinecofor (CGL2011-27229) Research Projects. We wish to thank the Castilla y León Regional Govt. for their help with the sampling, as well as the assistance provided by Eugenio A. Alonso Herbias and Carlos Morla in the preparation and treatment of the cross sections. Andrés Díez made interesting comments that have undoubtedly helped us to transmit the information, and Aitor Gaston helped us with Fig. 1 and E. Sadornil with some statistical analyses. We also thank the comments of the anonymous reviewer. Thanks to all the trees that gave us their history and which no longer exist due to the fire.

Appendix

See Table 3.

Table 3 Characteristics of the samples analyzed

ID	DBH	RF	TS	NS	MNT	MTW	Time span	MS	IT
1	86	*L*	*C*	2	81	3.37	1925–2005	0.261	0.698
2	61.1	*L*	*C*	2	99	2.38	1909–2007	0.268	0.749
3	64.3	*L*	*C*	2	86	2.23	1922–2007	0.177	0.626
4	55.7	*L*	*C*	2	77	1.91	1931–2007	0.235	0.686
5	77.4	*L*	*C*	2	99	3.44	1910–2008	0.236	0.623
6	62.7	*M*	*C*	2	113	1.95	1896–2008	0.249	0.565
7	62.4	*L*	*C*	2	106	2.91	1903–2008	0.259	0.666
8	65	*M*	*C*	2	109	1.50	1900–2008	0.317	0.518
9	55.4	*L*	*C*	2	71	0.98	1938–2008	0.169	0.628
10	70.1	*L*	*C*	2	114	1.74	1895–2008	0.276	0.667

Table 3 continued

ID	DBH	RF	TS	NS	MNT	MTW	Time span	MS	IT
11	107	*M*	*C*	2	78	2.60	1931–2008	0.198	0.7
12	125.2	*V*	*C/S*	31	148	2.98	1861–2008	0.321	0.675
13	76.4	*V*	*C/S*	25	120	2.40	1889–2008	0.258	0.703
14	133.8	*L*	*S* (2)	19	112	2.80	1897–2008	0.185	0.788
15	72	*V*	*S*	13	152	2.10	1857–2008	0.349	0.604
16	75.2	*M*	*S*	25	103	2.58	1906–2008	0.202	0.822
17	81.2	*L*	*S*	8	131	2.58	1878–2008	0.302	0.485
18	77.7	*L*	*S*	13	119	2.67	1890–2008	0.224	0.692
19	64.6	*L*	*S*	9	131	2.04	1878–2008	0.294	0.7
20	65.3	*L*	*S*	11	131	2.25	1878–2008	0.279	0.691
21	65.3	*V*	*S*	24	119	2.57	1890–2008	0.34	0.705
22	58.9	*L*	*S*	7	115	2.27	1894–2008	0.328	0.75
23	71.7	*V*	*S*	23	119	2.50	1890–2008	0.213	0.712
24	64.3	*L*	*S*	9	102	2.41	1907–2008	0.219	0.655
25	66.9	*N*	*C*	2	78	3.78	1930–2007	0.205	0.529
26	57.3	*N*	*C*	2	104	2.50	1905–2008	0.286	0.574
27	60.5	*N*	*C*	2	97	2.95	1912–2008	0.262	0.735
28	49	*N*	*C*	2	54	3.83	1955–2008	0.222	0.558
29	54.5	*N*	*C*	2	92	2.03	1917–2008	0.187	0.678
30	55.1	*N*	*C*	2	89	2.38	1920–2008	0.213	0.789
31	60.8	*N*	*C/S*	11	115	2.07	1894–2008	0.212	0.65
32	57.3	*N*	*S*	7	103	3.49	1906–2008	0.187	0.798
33	63.1	*N*	*S*	5	120	2.22	1889–2008	0.267	0.628
34	55.1	*N*	*S*	13	65	3.11	1944–2008	0.243	0.558
35	61.8	*N*	*S*	5	93	3.15	1916–2008	0.247	0.518
36	55.7	*N*	*S*	4	112	1.92	1897–2008	0.297	0.729

DBH diameter at breast height (cm), *RF* resin faces outwardly observed (*L* = 1–2 resin faces, *M* = 3–4 resin faces, *V* = 5–10 resin faces, *N* = none), *TS* type of samples (*C* = increment cores, *S* = cross sections), *NS* number of series, *MNT* maximum number of tree rings, *MTW* mean tree-ring width, *MS* mean sensitivity, *IT* intercorrelation (Cofecha program)

References

Alcalde C, García-Amorena I, García Álvarez S, García Calvo D, García García R, Génova M, Gil Borrell P, Gómez Manzaneque F, Maldonado J, Morla C, del Nido J, Postigo JM, Regato P, Río S, Roig S, Rubiales JM, Sánchez Hernando LJ (2006) Contribución de la Paleofitogeografía a la interpretación del paisaje vegetal ibérico: estado de conocimientos y nuevas perspectivas de investigación. Inv Agrar-Sist Rec F, Extra 15:40–50

Alía R, Martín S, de Miguel J, Galera R, Agúndez D, Gordo J, Salvador L, Catalán G, Gil L (1996) Las regiones de procedencia de *Pinus pinaster* Aiton. Ministerio de Medio Ambiente, Madrid

Alía R, Moro J, Denis JB (1997) Performance of *Pinus pinaster* provenances in Spain: interpretation of the genotype by environment interaction. Can J For Res 27(10):1548–1559

Ballesteros JA, Stoffel M, Bodoque JM, Bollschweiler M, Hitz O, Díez-Herrero A (2010) Changes in wood anatomy in tree rings of *Pinus pinaster* Ait. following wounding by flash floods. Tree Ring Res 66(2):93–103

Biondi F, Waikul K (2004) Dendroclim 2002: AC ++ program for statistical calibration of climate signals in tree-ring chronologies. Comput Geosci 30:303–311

Bogino S, Bravo F (2008) Growth response of *Pinus pinaster* Ait. to climatic variables in central Spanish forests. Ann For Sci 65:506–518

Bogino S, Bravo F (2009) Climate and intraannual density fluctuations in *Pinus pinaster* subsp. *mesogeensis* in Spanish woodlands. Can J For Res 39:1557–1565

Calama R, Tomé M, Sánchez-González M, Miina J, Spanos K, Palahí M (2010) Modelling non-wood forest products in Europe: a review. For Syst 19(SI):69–85

Caminero L (2009) Estudio dendroecológico de *Pinus pinaster* Ait. en Moral de Hornuez (Segovia). DEA Project (inedit.)

Candel-Pérez D, Linares JC, Viñegla B, Lucas-Borja ME (2012) Assessing climate–growth relationships under contrasting stands of co-occurring Iberian pines along an altitudinal gradient. For Ecol Manage 274:48–57

Choi YD (2004) Theories for ecological restoration in changing environment: toward ''futuristic'' restoration. Ecol Res 19:75–81

Choi YD (2007) Restoration ecology to the future: a call for new paradigm. Restor Ecol 15:351–353

Cook ER, Holmes RL (1996) Guide for computer program ARSTAN. In: Grissino-Mayer HD, Holmes R, Fritts HC (eds) The international tree-ring data bank program library version 20 user's manual. Laboratory of Tree-Ring Research, University of Arizona, Tucson, pp 75–87

Cook E, Kairiukstis L (1990) Methods of dendrochronology. Applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, p 393

Costa M, Morla C, Sainz Ollero H (eds) (1997) Los bosques ibéricos. Una interpretación geobotánica. Planeta, Barcelona, p 572

De Micco V, Saurer M, Aronne G, Tognetti R, Cherubini P (2007) Variations of wood anatomy and d13C within-tree rings of coastal *Pinus pinaster* showing intra-annual density fluctuations. IAWA J 28:61–74

De Miguel M, de Maria N, Guevara MA, Diaz L, Sáez-Laguna E, Sánchez-Gómez D, Cervera MT (2012) Annotated genetic linkage maps of *Pinus pinaster* Ait. from a Central Spain population using microsatellite and gene based markers. BMC Genomics 13(1):527

Díez-Herrero A, Ballesteros JA, Ruiz-Villanueva V, Bodoque J (2012) A review of dendrogeomorphological research applied to flood risk analysis in Spain. Geomorphology 196:211–220

El Khorchani A, Gadbin-Henry C, Bouzid S, Khaldi A (2007) Impact de la sécheresse sur la croissance de trois espèces forestières en Tunisie (*Pinus halepensis* Mill., *Pinus pinea* L. et *Pinus pinaster* Sol.). Sécheresse 18:113–121

Farjon A (2008) A natural history of conifers. Timber Press Inc, Portland

Génova M (2007) El crecimiento de *Abies pinsapo* y el clima de Grazalema: aportaciones dendroecológicas. Investigacion agraria. Sistemas y Recursos forestales 16(2):145–157

Génova M (2012) Extreme pointer years in tree-ring records of Central Spain as evidence of climatic events and the eruption of the Huaynaputina Volcano (Peru, 1600 AD). Clim Past 8:751–764

Génova M, Caminero L (2009) Effects of the management on tree-ring growth of *Pinus pinaster*. Abstr Eurodendro 2009:97

Génova M, Moya P (2012) Dendroecological analysis of relict pine forests in the centre of the Iberian Peninsula. Biodivers Conserv 21(11):2949–2965

Gil L (1991) Consideraciones históricas sobre *Pinus pinaster* Ait. en el paisaje vegetal de la Península Ibérica. Estud Geogr 202:5–27

González-Martínez SC, Mariette S, Ribeiro MM, Burban C, Raffin A, Chambel MR, Ribeiro CAM, Aguiar A, Plomion C, Alía R, Gil L, Vendramin GG, Kremer A (2004) Genetic resources in maritime pine (*Pinus pinaster* Aiton): molecular and quantitative measures of genetic variation and differentiation among maternal lineages. For Ecol Manage 197(1):103–115

Holmes R (1992a) Users manual for program Cofecha by Laboratory of Tree-Ring Research. University of Arizona, Tucson

Holmes R (1992b) Dendrochronology program library. Installation and program manual. Laboratory of Tree-Ring Research, University of Arizona, Tucson

Holmes R (1999) Program JOLTS: finding growth surges or suppressions in trees. Laboratory of Tree-Ring Research, University of Arizona, Tucson

Jackson ST, Hobbs RJ (2009) Ecological restoration in the light of ecological history. Science 325(5940):567–569

Lageard JGA, Thomas PA, Chambers FM (2000) Using fire scars and growth release in subfossil Scots pine to reconstruct prehistoric fires. Palaeogeogr Palaeoclimatol Palaeoecol 164(1–4):87–99

Lorimer CG, Frelich LE (1989) A methodology for estimating canopy disturbance frequency and intensity in dense temperate forests. Can J For Res 19(5):651–663

McBride JR (1983) Analysis of tree rings and fire scars to establish fire history. Tree Ring Bull 43:51–67

Nanos N, Tadesse W, Montero G, Gil L, Alía R (2000) Modelling resin production distributions for *Pinus pinaster* Ait using two probability functions. Ann For Sci 57:369–377

Nanos N, Tadesse W, Montero G, Gil L, Alía R (2001) Spatial stochastic modelling of resin yield from pine stands. Can J For Res 31:1140–1147

Rinn F (2003) TSAPWin: time series analysis and presentation for dendrochronology and related applications, version 0.53: user reference. RinnTech, Heidelberg

Rodríguez R, Serrada R, Lucas JA, Alejano MR, del Río M, Torres E, Cantero A (2008) Selvicultura de *Pinus pinaster* Ait. subsp. *mesogeensis* Fieschi & Gaussen. In: Serrada R, Montero G, Reque JA (eds) Compendio de Selvicultura Aplicada en España. INIA (Instituto Nacional de Investigaciones Agrarias), Madrid, pp 399–430

Rozas V (2004) A dendroecological reconstruction of age structure and past management in an old-growth pollarded parkland in northern Spain. For Ecol Manage 195:205–219

Rozas V, Lamas S, García-González I (2009) Differential tree-growth responses to local and large-scale climatic variation in two *Pinus* and two *Quercus* species in northwest Spain. Ecoscience 16(3):299–310

Rozas V, García-González I, Zas R (2011) Climatic control of intra-annual wood density fluctuations of *Pinus pinaster* in NW Spain. Trees 25:443–453

Sánchez-Gómez D, Majada J, Alía R, Feito I, Aranda I (2010) Intraspecific variation in growth and allocation patterns in seedlings of *Pinus pinaster* Ait. submitted to contrasting watering regimes: can water availability explain regional variation? Ann For Sci 67:505

Sánchez-Salguero R, Navarro-Cerrillo RM, Camarero JJ, Fernández-Cancio Á (2010) Drought-induced growth decline of Aleppo and maritime pine forests in south-eastern Spain. For Syst 19(3):458–470

Schweingruber FH (1993) Trees and wood in dendrochronology, Springer series in Wood Science. Springer, Berlin, p 474

Schweingruber FH (1996) Tree-rings and environment: dendroecology. Paul Haupt, Bern

Servicio Territorial de Medio Ambiente y Ordenación del Territorio de Segovia (1992) 4ª Revisión del Proyecto de Ordenación, 1993–2002, Grupo 8° de Ordenación. Consejería de Medio Ambiente y Ordenación del Territorio. Junta de Castilla y León. (inéd.)

Stoffel M, Bollschweiler M, Butler DR, Luckman BH (2010) Tree rings and natural hazards—a state-of-the-art. Springer, Dordrecht

Tadesse W, Nanos N, Auñon FJ, Alfa R, Gil L (2001) Evaluation of high resin yielders of *Pinus pinaster* AIT. For Genet 8:271–278

Timbal J (2002) Analyse rétrospective de la croissance radiale et mise en relation avec le bilan hydrique dans un dispositif d'intensité d'éclaircie de pin maritime dans les Landes de Gascogne. Ann For Sci 59(2):205–217

Van Horne ML, Fule PZ (2006) Comparing methods of reconstructing fire history using fire scars in a southwestern United States ponderosa pine forest. Can J For Res 36:855–867

Vieira J, Campelo F, Nabais C (2009) Age-dependent responses of tree-ring growth and intra-annual density fluctuations of *Pinus pinaster* to Mediterranean climate. Trees 23:257–265